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Method for synchronizing remote clocks to a central clock via satellite

Description

In recent times, satellite-based time signals are being increasingly emitted in addition to terrestrially emitted time signals, e.g. DCF-77. The most well known methods are the GPS system and the GLONASS system.

A serious disadvantage is the necessity of highly accurate satellite positioning and exact knowledge of the transmission path, especially of the ionosphere and troposphere, which is indispensable to a user requiring maximum accuracy. In addition, the satellite signals are deliberately corrupted for civilian users ("selective availability") in order to prevent non-military utilization requiring maximum accuracy. Methods have been developed which allow for partial compensation to these uncertainties (e.g. differential GPS). The difficulties relating to using the GPS signal for high-precision time applications have so far not been satisfactorily solved.

The said methods are widely used because of the inexpensive availability of suitable receiving devices. An operational disadvantage is seen in just this military nature of the systems which impede industrial utilization. Satellite-based time signals require an extensive infrastructure for monitoring and verification. A further disadvantage is that

high-precision data are available only with time delays of hours or longer from the said systems.

The two-way method (TWSTFT, Two-Way Satellite Time and Frequency Transfer) for time transmission is particularly suitable for metrological purposes. It is a method used by national calibration authorities (e.g. PTB Brunswick) for comparing existing time scales based on atomic clocks.

The advantage of this method lies in the basic independence of satellite position and of errors due to the transmission path. It can be derived directly from the symmetry of the method. Since both partners of a connection need both a transmitting and a receiving device, the application of the method is restricted to a few national authorities (D, UK, F, OE, USA, IA, IT, ES, NL) because of the relatively high expenditure.

The increasing availability of small inexpensive satellite ground stations with transmitting device now pushes the system-related disadvantages more and more into the background. It seems natural to make the two-way method, which has been successful for years, accessible to widespread use as an alternative to one-way methods (GPS, GLONASS).

A barrier to this has previously been that the 2-way method, also called TWSTFT (Two-Way Satellite Time and Frequency Transfer) was restricted to the comparison of existing clocks

located externally to the devices described here and that the measurement results are only published with a time delay of up to several days after corresponding calculations by the BIPM (Bureau International des Poids et Mesures, Paris).

These disadvantages are eliminated by the method by means of five essential innovations:

1. In the remote station, there is a physical clock with additional power reserve. Thus, it is no longer necessary to have a highly accurate external clock as previously in the case of 2-way time transfer but the clock installed directly in the device is used.

2. The signals used for time transmission are at the same time used for the bi-directional exchange of the 2-way measurement data.

3. Due to the continuously updated measurement data, the remote clock synchronizes to the central clock via a control loop by applying the system-related corrections which are also exchanged between the stations.

4. The time and frequency information available at the remote clock is available to the user in the form of externally accessible electrical signals.

5. The quality of synchronization can be checked with

minimum time delay due to the continuous updating of the measurement data.

The user derives the following advantages from the method:

1. Independence of infrastructures having military and/or multinational character.

2. There is no impairment of the data quality deliberately introduced for military reasons ("Selective Availability").

3. Utilizing the measurement method according to the 2-way principle which has been introduced, the system ensures a high degree of independence of the satellite position. It operates without knowledge of the propagation time along the transmission path.

4. The quality of the clock installed in the remote station can be much lower and less expensive in comparison with atomic clocks since this clock is matched to the central clock by means of a continuous control loop.

5. The method is suitable, in particular, also to prevent system drift with such a reliability which is not possible for reasons of principle in practical operation even with commercial atomic clocks of maximum quality.

6. The method operates in real time without elaborate reprocessing of the data.

7. The user has access to time signals which can be used directly.

8. The method has calibration quality due to a direct relation to a recognized time scale.

9. The measuring method is directly accessible to calibration.

The object of the invention is, therefore, a method and a device for synchronizing remote clocks to a central clock via satellite.

This object is achieved by means of a device of claim 1a and by a method having the features of claims 1b) to 1i).

The invention is described in greater detail with reference to figure 1. Figure 1 shows an example of a simple combination consisting of a central clock (1) in a satellite ground station (5) and a remote clock (2) in another satellite ground station (11), a control signal (17) being obtained by means of suitable measuring apparatus consisting of a transmitting (7) and receiving unit (8) in the central station and the corresponding transmitting (12) and receiving unit (13) in the remote station, in such a manner that the

remote clock (2) is synchronized with the central clock (1) in state and rate. For this purpose, both stations are connected with a bi-directional radio link (9.1) and (9.2) via a satellite (10) and exchange the results (15, 16) from time difference measurements (6, 14) in real time in both stations directly via the radio link (9.1, 9.2) via which the time signals of the stations are also exchanged. The correcting variable of the control loop (17) is formed from the difference of the two time difference measurements in the remote ground station. It influences the frequency of the remote clock (2). The reference time (3) of the central clock is provided to the user at the remote clock in the form of time signals (18).

The symmetry of the overall configuration and of the radio link are determining for the elimination of the unknown time delays of the transmission path and by the satellite.